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ACOSS ELEVEN (ACTIVE CONTROL OF SPACE STRUCTURES)

The Charles Stark Draper Laboratory, Inc.

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ACOSS ELEVEN (ACTIVE CONTROL OF SPACE STRUCTURES), Volume I

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The Active Control of Space Structures (ACOSS) Eleven contract includes three distinct areas of endeavor: Simulations Extension, HALO Optics and ACOSS. This report covers the work performed in each of these areas between May and November 1981. Simulations Extension and HALO Optics are presented in Volume I and ACOSS is presented in Volume II.

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LIST OF ACRONYMS

AVD	Air-Vehicle Detection
CSDL	The Charles Stark Draper Laboratory, Inc.
DARPA	Defense Advanced Research Projects Agency
DIS	Draper Integrated Simulations
DISCOS	Dynamic Interaction Simulation of Structures
DMA	Defense Mapping Agency
FFT	Fast Fourier Transform
GSS	Generic Scene Simulation
HAC	Hughes Aircraft Corporation
IFOV	Instantaneous Field of View
IMSL	International Mathematical and Statistical Libraries
IR	Infrared
LOS	Line of Sight
LS	Least Squares
lsc	Lower Semicontinuous Function
LSS	Large Space Structures
OTF	Optical Transfer Functions
PRA	Photon Research Associates
PSF	Point-Spread Function
TPBVP	Two-Point Boundary Value Problem
wlsc	Weakly Lower Semicontinuous Function
wslsc	Weakly Sequentially Lower Semicontinuous Function

SECTION 1

INTRODUCTION

The Active Control of Space Structures (ACOSS) Eleven contract includes three distinct areas of endeavor: Simulations Extension, HALO Optics, and ACOSS. This report covers the work performed in each of these areas between April and September 1981. A brief introduction to each of the tasks covered follows.

1.1 Simulations Extension

In order to generalize the HALO-oriented portions of the Draper Integrated Simulations (DIS) and simulate other useful surveillance concepts, CSDL initiated three major activities during this reporting period:

(1) Initial planning with DARPA to select surveillance systems concepts to simulate and evaluate.

(2) Establishing the capability to generate and manipulate synthetic scenes in house as well as support DARPA in standardizing key scene data bases.

(3) Extending the current DIS algorithms to handle a wider class of input scene data sets.

The Gemini concept, being developed by Aerojet Electro Systems, is the only system presently identified for simulation and evaluation. As first order Gemini models become available, they will be incorporated into the DIS.

A "generic scene generation" capability is being established as part of the DIS to extend its range of applications. Initially, the simulation will contain a data base that is a geometric representation of an ~40 × 40 km region in Southern California and it will have a spatial resolution of ~100 m. A set of four prescriptions will allow this data set to represent typical scenes from the Soviet tundra, the Arctic, the Middle East, and Central Europe with a limited capability to generate clouds and superimpose them on any geographic region.

Photon Research Associates (PRA), under subcontract to CSDL, is developing four standardized surveillance scenes to assess various surveillance systems concepts. DARPA will gain a baseline to compare system performance evaluations for common missions and a procedure to identify the scene/system characteristics that are performance drivers from this work.

1.2 HALO Optics

Three contractors, Eikonix Corporation, Itek Corporation, and Hughes Aircraft Corporation (HAC), have been working on the general deconvolution problem which is classified as the HALO Optics task of this contract. Eikonix has worked on the phase retrieval problem where aberrations are determined

from the focal-plane data; Itek has used a wavefront sensor to measure the system aberrations; and HAC has used "color" algorithms on the focal plane data to obtain optical system correction.

During this reporting period, CSDL developed a computer simulation to generate noisy and aberrated focal-plane point-spread-function (PSF) data under guidelines from Eikonix.

CSDL also prepared a phase retrieval test based on aberrations derived from cryogenic deformations of an Itek HALO mirror. The aberrated PSF was sampled by an 8 × 8 array of square detector elements, each of which had a full width of 2.13 λF. Three test cases were run. Case 1 had Gaussian random noise which had a uniform 2-percent standard deviation of the peak diffraction-limited signal. In Case 2, the PSF was decentered such that the peak irradiance of the diffraction-limited point spread function was moved to correspond to a line-of-sight error of (0.984 λ/D, -0.984 λ/D), where D is the diameter of the system pupil. As before, Case 2 had 2-percent noise. In Case 3, there was no line-of-sight error, but the noise was increased to 5 percent.

HAC reviewed their work on OYSTER, color algorithms, image moments, CORRWAVE, and phase retrieval at DARPA in May of 1981. CSDL will prepare test cases for the HAC color algorithms during the third year of the ACOSS 11 program.

1.3 Active Control of Space Structures (ACOSS)

Volume 2 of this report describes the work CSDL has done to investigate spacecraft control theory. Each of the six sections devoted to ACOSS reports on a different aspect of that work.

Section 4, "Compensated Truncation of Modal Models for Design of Control Systems," describes the selection process necessary in large space structure (LSS) control-system design using a truncated finite-element model. The truncated model must be selected properly and compensated explicitly for control and observation spillover, so the control system designed through this method can perform satisfactorily when implemented on the structure. Proper selection requires correct classification of structural modes into "primary" and "secondary" modes. Explicit compensation for truncation includes: placement of actuators and sensors, synthesis of the actuator and sensor influences once they are placed on the structure, and filtering of the actuator inputs and sensor outputs.

Section 5, "Ensuring Full-Order Closed-Loop Stability in the Reduced-Order Design of Output Feedback Controllers," builds on the studies performed during ACOSS 6 that established various conditions necessary to ensure full-order closed-loop asymptotic stability and robustness with reduced-order design of velocity and displacement output feedback controllers. Currently, the work in this area concentrates on how to apply such results to large flexible space structures and how to develop a reduced-order design technique that will ensure full-order closed-loop asymptotic stability.

The study includes preliminary development of computer-aided design software and acceleration output feedback control.

Section 6, "Design Freedom and the Implementation of Suboptimal Output Feedback Control," discusses the freedom inherent in design. The section states that often this freedom is sacrificed purposely when simplifying assumptions are made to avoid theoretical or computational difficulties. Since it is difficult to consider this topic without referring to specific applications, the section uses controller design as an example where work is being done to discover and exploit the freedom of choice in design. Then, the section uses suboptimal output feedback control as a case study which is relevant to ACOSS development.

Section 7. "Stochastic Output Feedback Compensators for Distributed Parameter Structural Models," presents recent progress on the stochastic output feedback design problem for distributed parameter plants. The results presented are an extension of work done under the previous contract.

The concepts developed are general enough to apply to a wide variety of fixed-form compensator design problems, and current studies are aimed at specializing the results to the optimal output feedback compensator design problem. The procedure developed will be applied to the design of velocity feedback controllers for a vibrating string. The results of this simple test should provide insight into the impact of various modeling assumptions on the convergence of the design procedure described.

Section 8, "Large-Angle Spacecraft Slewing Maneuvers," further develops work that was reported in the previous ACOSS contract. Specifically, the section presents techniques for improving the optimal torque profiles by allowing the solution process to determine the optimal terminal boundary conditions and by developing a control-rate penalty technique for producing smooth control profiles. Several example maneuvers are provided to demonstrate the practical application and utility of the techniques presented.

Section 9, "Order Reduction by Identification—Some Analytical Results," attempts to characterize control designs that will guarantee stability using a reduced-order model. This kind of design compromise is practiced regularly, but no one has verified the validity of such an approach.

The least squares (LS) method is used in this analysis because it is a relatively robust identification scheme and analytical expressions for order reduction already exist for it. The results of the analysis show that a reduced order controller can be built using the LS method of identification. It is planned to demonstrate the practicality of this approach on Draper Model #2 in the near future.

SECTION 2

SIMULATIONS EXTENSION

2.1 Introduction

The basic objective of the Simulations Extension Project is to generalize the HALO-oriented portions of the Draper Integrated Simulations (DIS) and to simulate other useful surveillance concepts. Three major activities have been initiated during the current reporting period:

(1) Initial planning with DARPA to select candidate surveillance systems concepts to simulate and evaluate.

(2) Establishing an in-house capability for generating and manipulating synthetic scenes as well as supporting DARPA in standardizing key scene data bases.

(3) Extending the currently implemented algorithms in the DIS to effectively and efficiently handle a wider class of input scene data sets.

Presently, the only system that has been identified clearly for simulation and evaluation is the Gemini concept under development by Aerojet Electro Systems. As this concept is defined further and first-order models become available, they will be incorporated into the DIS.

The bulk of the work performed on the Simulations Extensions Project during the current reporting period has been in the other two areas of endeavor, and this is discussed in detail in the sections that follow.

2.2 Generic Scene Simulation

The DIS is a sophisticated analysis tool for overall evaluation and performance assessment of space-based surveillance systems; it models the mechanical, optical, control, signal collection, and signal processing subsystems in detail in a highly interactive fashion. Currently, the range of DIS applications is limited because suitable data bases appropriate for the problem to be studied are unavailable. As a first step in overcoming this limitation and enhancing the simulation's capability to respond to DARPA analysis needs, a generic scene generation capability is being established as part of the DIS. Initially, this capability will enable the DIS to generate and manipulate a limited number of synthetic terrestrial scene data sets as a function of major surveillance system and mission parameters. Ultimately, it is planned to interface the generic scene simulation (GSS) with the Defense Mapping Agency (DMA) data base and to use this data base as the source for scene data input to the simulation. Draper has placed Photon Research Associates (PRA) under subcontract to help achieve these objectives. Some of the GSS features are discussed in the following paragraphs.

The simulation user will be able to vary independently the position of the observer (i.e., altitude and location), position of the scene, position of the sun (including night conditions), material types, width and location of the spectral interval (within the limits of 2.5 and 13 μm), and observer field-of-view and resolution with respect to the scene.

Initially, the simulation will contain a data base that is the geometric representation for one generic scene. When related to the earth's surface, the geometric representation will correspond to an approximately 40 × 40 kilometer geographic region in Southern California. The scene spatial resolution will be approximately 100 meters. A set of four prescriptions will be provided to enable this data set to be transformed into geometric representations typical of the following four geographical regions: Soviet tundra, Arctic, Middle East, and Central Europe. In addition, there will be a limited capability for generating clouds and superimposing them on any of the geographical regions.

The simulation will include a data base containing approximately 12 commonly found terrestrial materials as required for assigning characteristics to each facet of any of the five geometric representations cited above. The simulation will also include the LOWTRAN atmospheric model, a heat transfer module, and a solar ephemeris module for modeling the effects of solar and environmental heating on the scene.

2.3 Use of Standard Scenes

During the current reporting period, DARPA began an effort to standardize the scene data bases in use by the surveillance community to assess the performance of various surveillance systems concepts. The initial effort is directed toward the space-based air-vehicle detection (AVD) problem, and the baseline scenes to be used are summarized in Table 2-1. Each modeled scene will be an extension of measured data. In addition, each of the scenes will be modeled at two viewing angles, two times a day, and in four wavelength bands. PRA will perform the scene modeling effort for DARPA.

Use of the standard IR scene data base with the DIS will give DARPA a number of benefits, the most important of which are the following:

(1) A baseline for comparative system performance evaluations for common missions.

(2) A procedure for identifying the scene/system characteristics that are the key system-performance drivers.

The following steps outline a candidate approach for conducting comparative systems-performance evaluations.

(1) Identify a set of standard scenes appropriate for the systems to be compared/evaluated.

(2) Divide the "full" set of standard scenes into two subsets:

Table 2-1. Baseline standard scenes for the AVD mission.

Scene Type	Location	Description
Multi-Layer Clouds over Ocean	North Atlantic	Low altitude linear structured stratus, medium altitude cumulonimbus, and high altitude semi-transparent cirrus.
North Canada Melt Lakes	Canada Coastline below Beaufort	Low relief tundra with melt lakes surrounded by marsh land. Summer season.
Snow Covered Alaska Mountains	Brooks Range, Alaska	Moderate relief mountains on north coast of Alaska south of Beaufort Sea. Spring season.
Arctic Sea Ice	Beaufort Sea	Snow covered sea ice of varied thicknesses with cracks, including open water. Spring season.

(a) A generally available "public" set with targets with characteristics and trajectories that are specified openly.

(b) A "private" set containing targets with characteristics and trajectories that are known by only a limited group.

(3) CSDL and each systems contractor will use the "public" set to validate mutually one another's overall performance/simulation.

(4) Once agreement is reached with the "public" set, CSDL uses the validated simulation to generate a focal-plane output for scenes from the "private" set.

(5) CSDL and each systems contractor then independently simulate the signal-processor performance in target detection/acquisition.

Figure 2-1 schematically illustrates this process.

2.4 Enhanced Scene Processing

2.4.1 Introduction

As documented previously [2-1], the present version of DIS performs, in the spatial domain, the convolution of the scene radiance map with the optical system point-spread function (PSF) to obtain (in the spatial domain) the focal-plane irradiance. Precomputed image-plane convolution tables increase the efficiency of the algorithms for this technique. This approach was

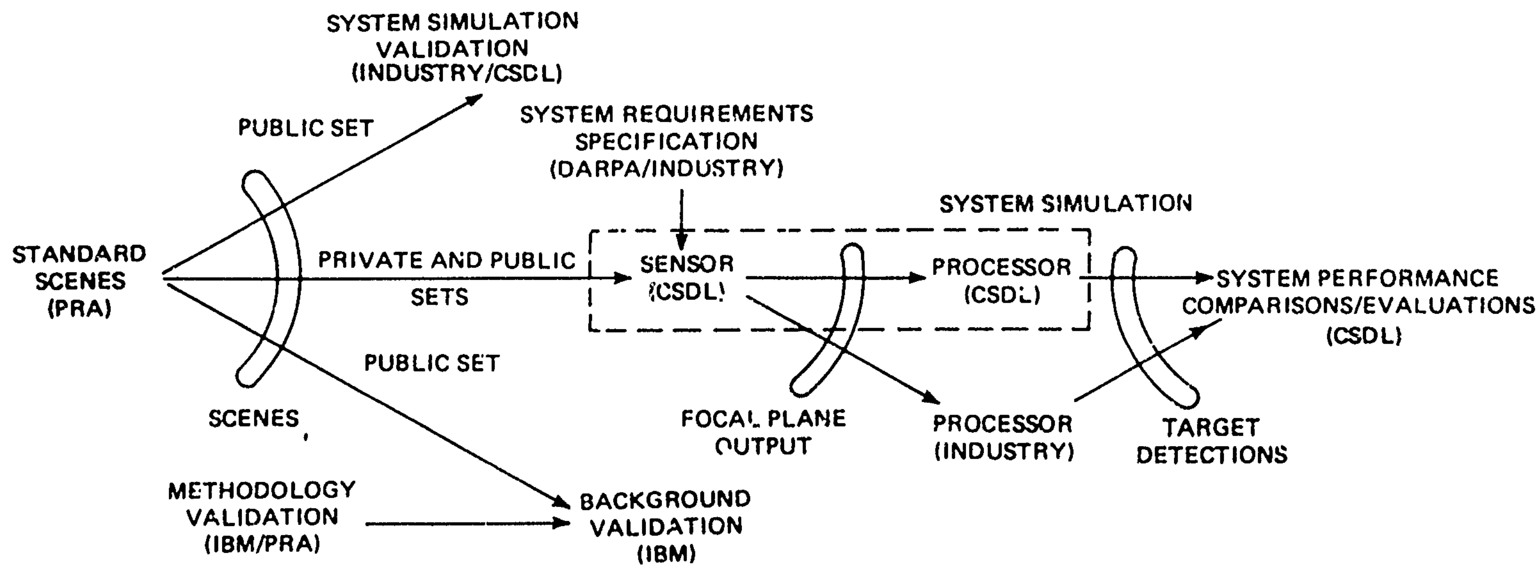

Figure 2-1. Roadmap for comparative systems performance evaluations using standard scenes and the DIS.

developed and implemented with the needs of Mini-HALO in mind. Typical Mini-HALO missions can be analyzed and simulated using this technique with reasonably modest expenditures of computer time.

In general, the computational effort required to process a given scene using this technique is a strong function of a number of parameters, the most important of which are as follows: Scene extent (i.e., field-of-view size); scene resolution; and line-of-sight perturbation characteristics (i.e., line-of-sight drift and jitter). Thus, compared to Mini-HALO, the surveillance-system simulations with large fields-of-view and/or high-resolution sensors and/or large line-of-sight perturbations can require prohibitively long computer time. The Gemini system discussed in Section 2.1, which requires high-resolution scenes, is a case in point. There are several approaches to generalizing the scene processing of the DIS.

2.4.2 Fourier Transform Approach

One approach employs Fourier Transform techniques. The scene is initially transformed into the spatial frequency domain using Fast Fourier Transform (FFT) algorithms. The result of this transformation is multiplied then by the transfer functions associated with the optical system and the sampling aperture of the focal-plane pixels. The steps up to this point need to be performed only once. Then, for each sequential focal-plane integration period, the phase coefficients of the transformed scene (in the spatial frequency domain) are perturbed to account for the effects of line-of-sight jitter and drift. Then the amount of data in this perturbed two-dimensional scene spectrum is compressed by a factor corresponding to the background-to-detector oversampling ratio and transformed back to the spatial domain to obtain the scene irradiance per detector at the focal plane during the integration period. For each sequential focal-plane integration period, the phase coefficients are updated to account for changes in the drift and/or jitter, and the process is repeated.

2.4.3 Image Plane Interpolation Approach

Another approach to generalizing the DIS scene-processing capability proceeds along the lines of the present spatial domain scene/PSF convolution approach, except the convolutions are performed selectively. Basically, the concept is to interpolate previously computed sets of focal-plane irradiance values to obtain those corresponding to new positions of the line-of-sight.

Indeed, the present approach requires that a new convolution be performed at each instant of time for which the line-of-sight changes, e.g., for each new line-of-sight jitter step. However, consider a scene (a subset of which is the instantaneous field of view (IFOV) of the sensor), and suppose a square reference grid is superimposed on the scene. For convenience, assume the dimensions of a particular element in this grid correspond to the projection of the sampling aperture of a focal-plane pixel. Further, suppose that this two-dimensional scene is oversampled (with respect to a focal-plane pixel) by a factor of M in each direction. Then an element in this reference grid will contain $M \times M$ scene elements.

At the start of the simulation run, select the element of the reference grid that contains the line of sight of the IFOV. Then, that line of sight also will lie somewhere in a square grid formed by four scene elements. If the four sets of focal-plane irradiance values are computed that correspond to the line of sight coinciding with each of the four scene elements, then the focal plane irradiance values for the actual line-of-sight position may be computed by two-dimensional interpolation in these four sets of irradiance values.

Consider the line-of-sight position at the next time step, and assume it was displaced by drift or jitter. Then, if the new line-of-sight position lies within the same square scene-element grid, the new set of focal-plane irradiance values may be obtained by interpolation into the previously computed four sets of irradiance values, and no new convolutions are necessary. If the new LOS position lies within an adjacent square scene-element grid, then two (or at most three) new convolutions would need to be performed before the interpolation could be conducted. However, since the end result required is the net focal-plane irradiance per pixel, at most $M \times M$ convolutions would be required to handle all LOS perturbations. By selecting the interpolation scheme appropriately (e.g., bilinear or bicubic spline), it may be possible to use a coarser grid of background samples, such as every other one, and hence reduce the total number of convolutions correspondingly, possibly to $M^2/4$. At each step in the process, the convolutions computed for the scene-element grid points are saved and are available for use in a later run. Thus, in a set of runs involving the same scene, the convolutions would need to be performed only for the first run.

LIST OF REFERENCES

2-1. HALO Integrated Simulations Program Final Technical Report, Vol. 1: Program Summary and HALO Integrated Simulations Development, CSDL Report R-1437, February 1981.

SECTION 3

HALO OPTICS

3.1 Introduction

In the current CSDL HALO program, the general deconvolution problem is classified as the HALO Optics task. Three contractors have been working on this problem. Eikonix Corporation has worked on the phase retrieval problem where aberrations are determined from the focal-plane data. Itek Corporation uses a wavefront sensor to measure the system aberrations. These errors are decomposed into mirror-figure errors which are then corrected with actuators on the mirrors. Hughes Aircraft Corporation (HAC) has worked on the problem of optical-system correction using "color" algorithms on the focal-plane data.

CSDL supports DARPA on HALO Optics technology by preparing tests for the deconvolution problem, evaluating the results, and assessing the performance. To date, only software tests have been prepared for Eikonix, although a hardware test is suggested in this report. For Itek and HAC, only software tests are planned in the current program.

In this report, a recent test is described that was prepared for Eikonix's phase retrieval algorithm. The preparation of the test and the results to date are discussed herein. It is pointed out that the aberrations retrieved by Eikonix do not represent a good estimate of the actual aberrations. When the retrieved aberrations are subtracted from the actual aberrations, i.e., when a correction is made, the residual aberrations are much worse. This fact has been reported to Eikonix. They have been given the actual aberrations to see if they can determine any error and if they can improve their system performance.

CSDL has applied this test to the image-sharpening algorithm with very encouraging results. The Strehl ratio of the image increased from 0.26 to 0.62 with one iteration of correction.

A hardware simulation should be set up to determine the limits of applicability of the phase-retrieval algorithms. A procedure by which this may be accomplished is outlined in this report.

Comments on a briefing to HAC also are reported herein.

3.2 Phase Retrieval Test

3.2.1 Phase Retrieval Technique

In the Eikonix phase retrieval algorithm, aberrations are estimated from the focal plane data by an iterative process in which a merit function

$$Q_1 = \int \left| \tau(\vec{\rho}) - \hat{\tau}(\vec{\rho}) \right|^2 d\vec{\rho}$$

or

$$Q_2 = \int [I(\vec{r}) - \hat{I}(\vec{r})]^2 d\vec{r}$$

is minimized. Here, $\tau(\vec{\rho})$ and $\hat{\tau}(\vec{\rho})$ are the aberrated and trial optical transfer functions (OTF), respectively, and $I(\vec{r})$ and $\hat{I}(\vec{r})$ are the corresponding point-spread functions (PSF). The function $I(\vec{r})$ is the measured focal plane distribution. $I(\vec{r})$ and $\tau(\vec{\rho})$ are related by a Fourier transform.

3.2.2 Test Preparation

3.2.2.1 Shortcomings of Previous Tests

In past tests, the PSF data was sampled by point detectors with a spacing of $\lambda F/5$. Here λ is the wavelength of the object radiation and F is the focal ratio (f#) of the HALO Optical system. Also, any noise in these sampled data was not considered. Thus, the finite size of the detector elements and system noise were not included because Eikonix algorithms had not matured to handle these aspects.

3.2.2.2 New Test

As the Eikonix algorithm developed further, CSDL improved its software to overcome the shortcomings of the previous tests. Under guidelines from Eikonix on the size of the detector element and array, CSDL developed a computer simulation to generate noisy and aberrated focal-plane PSF data. A flow chart of this simulation is shown in Figure 3-1.

CSDL prepared a phase-retrieval test based on aberrations derived from cryogenic deformations of an Itek HALO mirror. This mirror is circular with a diameter of 0.6 meter. It is ultra-lightweight and made from fused silica. The aberrated PSF was sampled by an 8 × 8 array of square detector elements, each element had a full width of $2.13\lambda F$. To this array of signals, Gaussian random noise was added which had a uniform standard deviation of 2 percent of the peak diffraction-limited signal. This test represented Case 1.

In another test, Case 2, PSF was decentered such that the peak irradiance of the diffraction-limited spread function was moved by ($-0.984\ \lambda F$, $-0.984\ \lambda F$) which corresponds to a line-of-sight error of ($-0.984\ \lambda/D$, $-0.984\ \lambda/D$), where D is the diameter of the system pupil. As before, 2-percent noise was added to the sampled data.

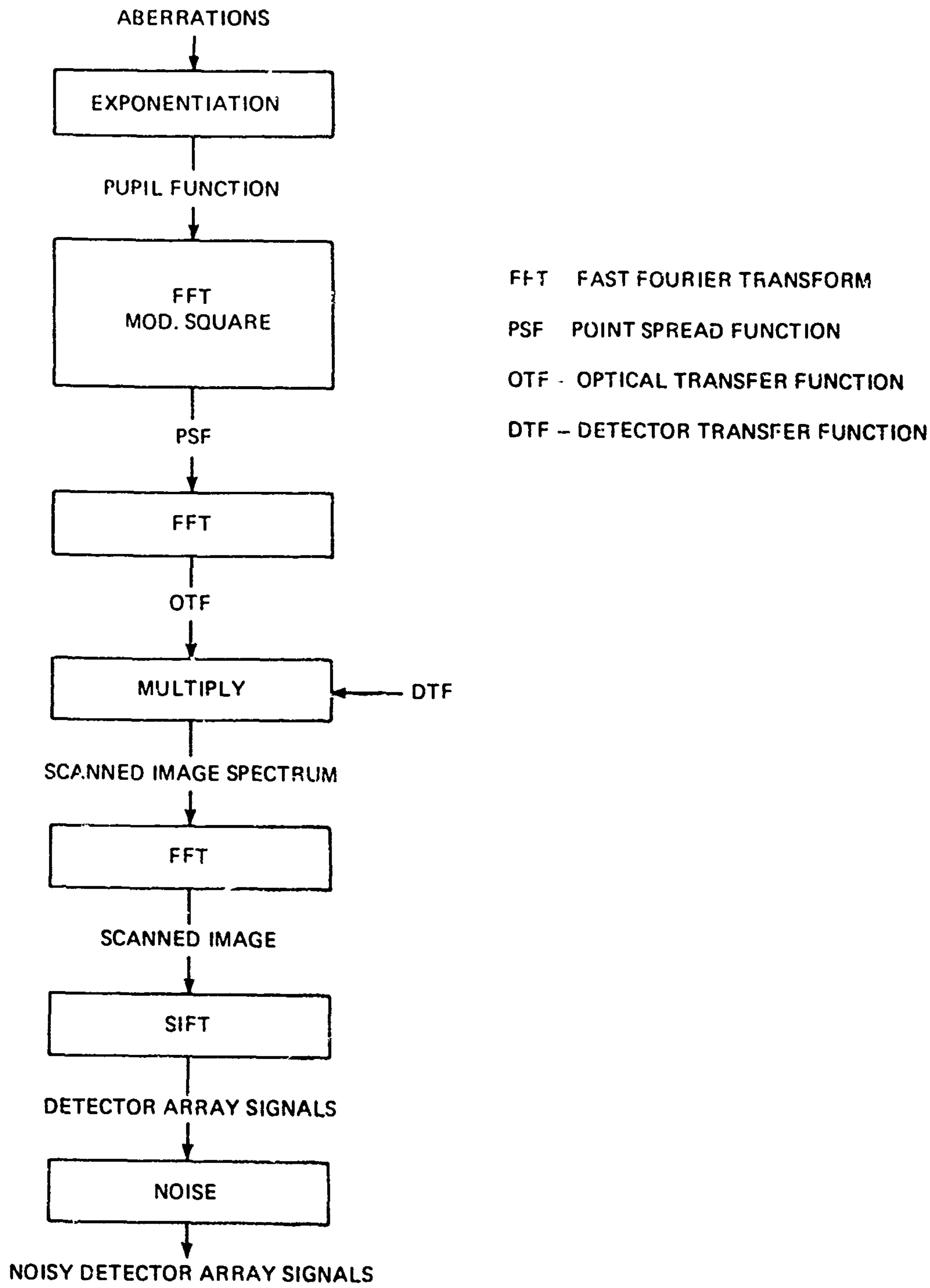

Figure 3-1. Flow chart of computer simulation for calculating noisy and aberrated focal-plane PSF data.

In the third test, Case 3, there was no line-of-sight error, but the noise was increased to 5 percent. The three 8 × 8 arrays of aberrated and noisy signals are shown in Table 3-1.

3.2.2.3 Preliminary Test Results

By using their algorithms, Eikonix estimated the aberrations from the detector array signals in terms of 8, 15, and 23 Zernike polynomial coefficients that did not agree with each other very much. They also differed wildly from case to case.

To compare the estimated with the actual aberrations, CSDL calculated aberrations at an array of points (within a circle) from the Zernike coefficients. When the estimated aberrations were subtracted from the actual ones, the residual aberrations were much worse than the actual ones in each case. Generally, the standard deviation of the aberrations increased from an initial value of 0.186 λ to approximately 0.4 λ.

3.3 Image Correction by Image Sharpening

3.3.1 Image Sharpening Technique

The image can be corrected in a closed-loop manner (as opposed to the open-loop operation of the phase-retrieval technique) by optimizing the sharpness functions obtained from the focal-plane data. If $I(\vec{r})$ represents the focal-plane image distribution, then sharpness functions

$$S_1 = \int I^2(\vec{r})\, d\vec{r}, \quad \text{Extended and Point Objects}$$

and

$$S_2 = \int_{\Delta\vec{r}} I(\vec{r})\, d\vec{r}, \quad \text{Point Objects}$$

attain their maximum values when the system is aberration free. The first sharpness function uses an array of detectors, but the second uses a single detector with a width approximately half the diameter of the Airy disc. Small amounts of aberration are introduced into the system in terms of Zernike modes until the sharpness function is maximized.

3.3.2 Hardware Demonstration

The image sharpening technique was demonstrated using an adaptive membrane mirror. Figure 3-2 is a schematic of the laboratory setup. Six Zernike modal corrections (defocus, spherical, two astigmatisms, and two comas) were introduced into the mirror. Figure 3-3 is an example of image correction.

Table 3-1. Noisy and aberrated detector signals sent to Eikonix. Case 1, centered PSF and 2-percent noise. Case 2, PSF decentered by (−0.9 84 λF, −0.984 λF) and 2-percent noise. Case 3, centered PSF and 5-percent noise.

Case 1

8	−18	−9	−5	−11	33	13	−7	−15
7	6	1	27	33	30	4	−3	0
6	−45	−16	2	29	179	12	27	0
5	14	−2	6	66	352	58	−15	−4
4	−2	12	1	61	95	58	−11	3
3	29	−20	3	16	34	13	5	15
2	−2	−8	26	35	11	−4	−19	−14
1	−16	−8	−12	−8	−15	−30	−6	−25

Case 2

8	26	−3	5	44	−13	−4	27	−22
7	−22	−33	4	21	11	5	−8	18
6	2	13	−11	−29	56	14	6	9
5	−10	3	10	102	240	29	13	1
4	−15	−13	41	209	164	5	−8	21
3	−2	11	16	−6	31	−2	0	16
2	−9	31	2	−12	20	−3	16	−1
1	−22	24	−8	−17	−21	−16	−25	10

Case 3

8	−34	−43	14	87	−16	−21	51	108
7	−30	41	22	−9	27	22	43	−7
6	−5	53	−81	−32	166	−27	24	−25
5	53	−63	7	13	375	29	13	40
4	57	−2	71	15	122	−2	14	69
3	16	21	−6	−60	56	−41	16	−14
2	8	−37	12	−2	−14	−94	−91	−40
1	34	−17	−58	45	−49	−41	−23	−70

Circular aperture center-to-center spacing and detector element size = 2.1328 in λF-number units. Find the aberrations in terms of Zernike coefficients.

The origin (0,0) lies at the encircled number, and the peak diffraction-limited signal is equal to 835. The noise is measured in terms of the peak diffraction-limited signal.

The two images shown in this figure represent the aberrated and corrected images of a point object.

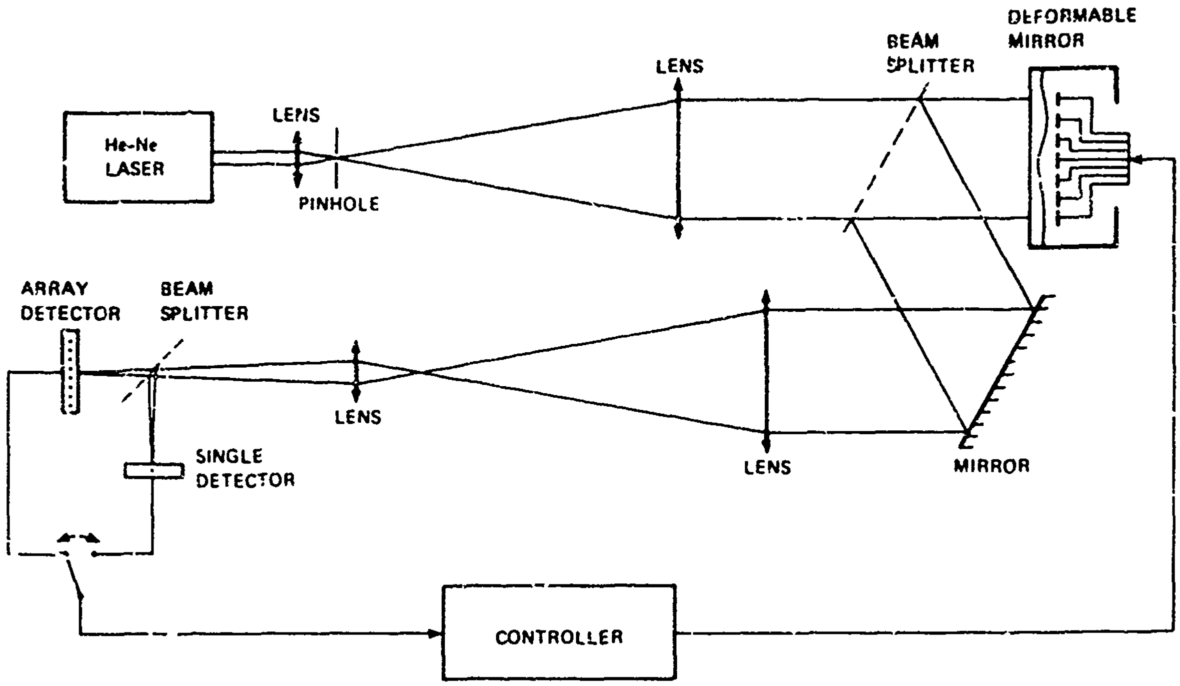

Figure 3-2. Schematic of laboratory setup for demonstration of the image sharpening technique.

3.3.3 Software Tests and Results

Test Case 1, prepared for Eikonix's phase retrieval test, was also used on the CSDL image-sharpening algorithm. Using the six Zernike modal corrections, the Strehl ratio of the PSF increased from 0.26 to 0.62 in one iteration.

3.4 Review of HAC Work on Image Correction Techniques

Sam Williams and his associates at HAC reviewed their work on OYSTER, color algorithms, image moments, CORRWAVE, and phase retrieval at DARPA on 13 May 1981. The phase-retrieval work was presented by R. Gonsalves of Eikonix as a subcontract to HAC.

The work presented consisted of computer simulation results supported by some experimental evidence. They felt confident that these methods would work under appropriate conditions. Unfortunately, these conditions were not described adequately. No comparison of the various techniques was presented, every technique seemed to hold promise. How a particular technique would work in practice was not discussed, that is, system related issues were completely absent.

(a) ABERRATED WAVEFRONT

(b) ABERRATED IMAGE

(c) CORRECTED IMAGE

Figure 3-3. Example of image correction by image sharpening.

HAC is interested in developing a test bed to test and compare their algorithms. From what has been reported, it seems that they have done enough testing, both in computer simulations and in the lab, to show that these techniques hold promise. These techniques should be reviewed and tested by an independent party. Per ACOSS II Statement of Work, Paragraph 4.1.4.4, CSDL will prepare test cases for the HAC color algorithms in the third year of the three year program. In a letter to RADC, CSDL recommended the following three-step approach.

(1) Prepare and Evaluate Test Cases (Computer Simulations)--To carry out this task, CSDL can work with HAC in the same way as work has been carried out with Eikonix. These tests will bring out algorithm subtleties and identify limitations.

(2) Prepare Deliverable Algorithms--Depending on the results of Task 1, HAC should prepare deliverable algorithms on their most promising approach(es).

(3) Algorithm Hardware Test--The delivered algorithms should be tested in a hardware simulation such as OPTECAL. Since OPTECAL is envisioned as a system-level optical-technology simulation, it can test, compare, and evaluate component technologies and algorithms.

3.5 Summary, Conclusions, and Recommendations

Table 3-2 summarizes the test case results and compares the phase-retrieval and image-sharpening techniques. It is evident that image sharpening has some inherent advantages.

Although Eikonix is still working on the test cases to improve the algorithm performance, the next step should not depend upon the outcome. As a minimum, a hardware simulation should be prepared to test the practical limits of the applicability of their algorithms. CSDL can prepare such a simulation using their in-house image-sharpening setup.

The adaptive membrane mirror needs to be repaired, and CSDL has the facilities to do this repair and make the mirror operational. Once the mirror is operational, the hardware facility can be used to investigate the image-sharpening technique to correct aberrated images of extended objects.

Table 3-2. Test case summary and comparison of phase-retrieval and image-sharpening techniques.

	Image-Plane Detector	Object	Operation	Test Case Results
Eikonix's Phase Retrieval	Array	Point, Yes Extended?	Open Loop	Corrected image much worse, σ_w increases from 0.18 to 0.44 λ
CSDL's Image Sharpening	• Single for point objects • Array for extended objects	Point, Yes Extended, Yes	Closed Loop	Six Zernike modal corrections increase Strehl ratio from 0.26 to 0.62 with one iteration

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